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RECENT DEVELOPMENTS IN TECHNIQUES, EQUIPMENT AND METHODS FOR GROUNDWATER PROSPECTING

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GEOLOGY

1. Throughout Australia, the search for and location of groundwater supplies is primarily one for the geologist, his work being assisted and augmented by the geophysicist, the chemist, and the driller.

2. The basis of all geological work is regional mapping, which is usually undertaken on scales of one inch to one mile (1:63,360) or one inch to four miles. This is followed by more detailed local mapping of each small area of interest, using aerial photographs.

3. Rocks of Palaeozoic or greater age are generally dense and strongly folded, their capacity to yield usable water in worthwhile supply being intimately dependent on the rock type, local structure and jointing, rainfall and topographic relief. All these influences have to be studied in assessing the potential of a particular area, this being the task of the field geologist.

4. The rock type affects groundwater salinity in two ways; one being the direct effect of certain rock minerals and their weathered products in making salts available for solution, the other an indirect effect resulting from joint development, which limits the movement of the groundwater. Jointing is also a major factor in controlling supplies, the hard and competent rock types such as quartzite having a relatively open joint system permitting freer movement of water than do the softer argillaceous rocks such as slates and mudstones.

5. The attitude of folded beds controls the selection of drilling sites, as water wells in hard rocks usually are not drilled deeper than 400-450 feet. It also governs the topography, controlling the development and direction of stream systems which may provide local intake along the valley floors, and affecting the fraction of surface run-off from the slopes.

6. Rainfall is important, it being not uncommon to find that rocks which in a 40-50 inch rainfall area yield groundwater with a salinity

of less than 500 p.p.m. may in a 20-25 inch rainfall contain 7000 p.p.m. water or worse.

7. All these factors must be considered by the field geologist when selecting well sites.

8. In sedimentary basins when the rocks are usually younger than Palaeozoic, folding is much less well developed, outcrops are often confined to the marginal areas, and problems of structure interpretation are best solved by test drilling either in a grid pattern or along selected section lines.

9. Outcrop mapping and levelling is important, because outcrops and subcrops are the intake and outlet zones. It is common to find that the rocks were deposited under saline water conditions, and will retain this original salt water unless it can be replaced by fresh water intakes from surface run-off. Field work therefore includes fairly detailed mapping of the basin margins, and investigation of any possible intakes in the basin centres such as may be provided by sink-holes in a karst topography, or stream lines and swamps.

10. The next step is drilling, which yields strata samples for palaeontological examination to elucidate the stratigraphy, water samples from which isohalsine maps are prepared, and water levels from which isopotential maps can be drawn. This is usually followed by the pump testing of selected bores to determine transmissibility of the aquifers. With all such information available, a complete picture of the basin can be arrived at, and its groundwater potential assessed.

11. Salinities are measured in two ways. The more general method is to collect water samples from pumped wells, and submit them for detailed chemical analysis in which the chloride, carbonate, sulphate, sodium, magnesium and calcium ions are determined, as well as more unusual ions when necessary.

SALINITY TESTING

12. The chemical methods used are those set out by the American Public Health Association.[5] As a preliminary to full analysis, the Specific conductance is determined, as being a measurement of the salt concentration. The apparatus comprises a Philips conductivity bridge, which measures the specific conductance between the electrodes of a cell compartment from a Dionic water tester, used because the Dionic cell has movable electrodes adjustable for temperature. This instrument, which is calibrated against a large number of chemically analysed samples by plotting average concentration against specific conductance, is not precise, since it assumes a constant ratio of ions throughout all waters tested. In the majority of waters this can be assumed, and the determination of "approximate total salts" by means of conductance yields quite useful results.

13. For use in boreholes where samples cannot be collected, a simple electrical probe has been developed, having a built-in thermistor to compensate for temperature variations. This probe, which has a diameter of 1.5 cm , can be lowered into small spaces on a cable, an A.C.

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[5] American Public Health Assoc., Standard methods for the examination of water, sewage and industrial wastes, 10th Edition, New York (1955).

voltage being obtained from a hand-operated Megger unit. It has been found particularly valuable in boreholes penetrating layers of differing salinities, or where salt water is leaking through a hole in the casing and contaminating the main supply, or where saline waters overlie better quality waters which they contaminate by downward movement in the well.

DRILLING

14. Percussion drilling is widely used and needs no description. One recent innovation in technique, however, is the use of a sequestering agent, sodium hexametaphosphate, during the process of development of a screened bore. This substance is mechanically forced down the bore and out into the aquifer around the screen, and then left for some hours, after which the supply is developed. It has been found very effective in removing clay material from a sandy aquifer, and supplies can commonly be increased to five or ten times their original value.

15. A second material has been used successfully for the chemical grouting of unconsolidated water-charged sands which tend to "blow" during drilling. This is a proprietary water soluble mixture of two organic chemicals, acrylamide and NN'-methylenebisacrylamide, mixed in proportions that will polymerize to stiff gels from dilute aqueous solutions, the action being controlled by catalysts. One limitation to its use is the need to place the whole of a mixed batch within the established induction period since if unexpected delays occur during pumping, gelation may occur before placement is achieved. It has an advantage over cement grout in being capable of much quicker handling through the pump, so that lightweight equipment can be used. It has particular value in drill holes for sealing off inflowing water and for preventing caving of strata in uncased holes, as well as the recovery of lost circulation in diamond drilling.

ELECTRIC WELL LOGGING

16. The only logging methods which would appear to be of value to the water well driller are the conventional Electric Log and the Radiation Log. Electric logging is of use only in uncased wells. In principle, the log is plotted against depth, the curve on the left showing in millivolts the spontaneous potential (S.P.) of the beds traversed, while on the right side is a family of curves (usually three) showing their resistivity at different distances from the borehole, in ohms per square metre per metre.

17. Spontaneous potential results from two causes, both dependent on seepage of the filtrate from the mud or fluid in the bore into porous beds. The first cause is an electromotive force (e.m.f.) set up when an electrolyte passes through a semi-permeable membrane (the mud sheath on the well walls) into another of different concentration. The second is an e.m.f. set up at the interface of two electrolytes of different concentrations. Both e.m.f.'s are proportional to the log of the ratio of the concentrations and are of the same sign.

18. The S.P. curve will show strong indentations when almost fresh drilling fluid diffuses into a salt water aquifer; will remain unaffected opposite permeable beds; and show reverse movement when the formation water is fresher than the drilling fluid.

19. The resistivity curves on the right hand side of the logs are

produced by passing an electric current through the formation between an electrode on the logging device and the ground surface, measuring the drop in e.m.f. between the two electrodes. By using electrodes spaced at different distances from one another, the resistivity at different distances from the borehole can be measured, these distances usually being 16 inches, 64 inches and 10 to 18 feet.

20. Clays and shales are conductive, since the water absorbed in the clay-mineral faces has a large content of electrolytes, but marine shales are commonly slightly more conductive than fresh water shales. Salt water sands are highly conductive, but fresh water sands are not.

21. The electric log can be used, by correlating corresponding curve indentations in different wells, for structural interpretation. Folding, warping, and tilting of the aquifer can be determined, and increasing shaliness of the aquifer or the salinity of its water can be mapped. Ordinarily, salinities can be calculated if the porosities are known, but as the limits between good and barely potable water are at the limits of accuracy of the method, such quantitive work may have little value. It may have a use in the drawing of contours.

22. Where fresh and salt waters are separated by a thin shale band, electric logs from different wells can show whether it is continuous, or lenticular and unlikely to effect a real separation of the two. The slight difference in resistivity between marine and fresh water shales may enable marine incursions into the water bearing formation to be mapped and areas of poorer water avoided.

23. In such work a small sonde and light logging outfit can be hired in any country from an internationally known American firm which specializes in such equipment.

GAMMA-RAY LOGGING

24. In bores that are cased or dry, neutron logs and gamma-ray logs are needed. Both have been used in Australia.

25. The apparatus for gamma-ray logging consists of a gamma-ray detector which is lowered down the borehole on the end of an electrical cable. The detector is a crystal of activated sodium iodide, which emits flashes of light when bombarded by the gamma-rays. The light flashes are changed into electrical impulses by a photomultiplier tube, the impulses being amplified in the recording truck and applied to a chart recorder, which gives a continuous record of the rate at which impulses are produced. The curve on the paper chart, therefore, shows the quantity of gamma radiation reaching the detector as it is lowered down the hole, and provides a measure of the natural radioactivity of the strata through which the detector is passing.

26. As the radiation emitted by any radioactive substance fluctuates from one moment to another it has to be averaged over a period of a second or two so as to give a fair estimate of the amount of radioactivity. The electrical circuits are designed to do this automatically, but the consequence is that the detector has to be lowered slowly to give it a reasonable time opposite each rock bed. The longer the time-constant of the equipment, the more faithful is the log, but the slower is the rate at which the hole can be logged in order not to miss the thinner beds. A time-constant of one second and a logging speed of 40 feet per minute are often used.

27. The radioactivity of rocks is due mainly to their minute content of uranium and thorium, but potassium, which is usually present in substantial quantities, also contains a small amount of radioactive isotope. It has been found that shale is generally the most radioactive of all sedimentary rock, sandstone and limestone being usually less so. Although some sandstones, particularly those that contain phosphates, can be more radioactive than most shales, the high gamma-ray counts on the log of a sedimentary sequence can in general be ascribed to shale, and the lower counts to sandstone or limestone.

28. The Great Artesian Basin, comprising two-thirds of Queensland and parts of neighbouring States has been drilled extensively, but drillers' logs of the bores do not give a reliable picture of the subsurface geology. To aid further drilling, more information is needed on the configuration of the aquifers, and a programme of gamma-ray logging of some hundreds of bores is now being undertaken by the Bureau of Mineral Resources to provide this information. Although the Mesozoic sandstones and shales in the Great Artesian Basin are continuous over vast distances, the sandstones often occur as lenses, so correlation is difficult unless the bores are close together.

29. The logs obtained to date have been from widely- spaced bores, but some of them enable correlations to be made. FIGURE I shows a suggested correlation of six bores in a line 100 miles long within the shallow Sub-basin, a part of the Great Artesian Basin. The aquifers belong to the Cretaceous and Jurassic formations known as the Blythesdale and Bundamba Groups. Some of the zones have been tentatively assigned formation names on the basis of a general geological account of the area by Whitehouse.[6]

30. Zone A is the best marker, and shows a sharp decrease in radioactivity from that of the layer above it, followed by an increase corresponding to shale. Zone B is marked at the top by a decrease in radioactivity, indicating sandstone, below which are numerous "troughs" corresponding to sandstone beds. This zone is probably the top of the Gubberamunda Sandstone, one of the principal aquifers in the Blythesdale Group, and Zone A probably corresponds to part of the Fossil Wood Horizon, which is known to overlie the Gubberamunda Sandstone.

31. There are evidently several facies changes in Zone B between the Darrawong and Queen's Birthday bores, which may account for the lack of water production from this zone in the three northernmost bores. Zone B can be considered continuous only because of the correlation of Zones A and C. The logs serve to show that the water horizons themselves cannot be correlated over wide distances. In the absence of the logs, a considerable dip might have been expected between the Darrawong and Queen's Birthday bores.

32. However, according to the suggested correlation the rock dips are in fact quite gentle. In an area of steeper dips correlation would be more difficult; hence the need for logging bores close together.

33. From this work it is apparent that gamma-ray logs from a closely-spaced group of existing water bores can be used to give a sub-surface picture of the various sandstones, even though the holes are cased. The logs give no indication of the porosity of the sandstones or of their water-producing capacity.

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6 Whitehouse, F.W., Artesian water supplies in Queensland: Appendix G - The geology of the Queensland portion of the Great Australian Artesian Basin, Govt. Printer, Brisbane, (1954).

THE NEUTRON MOISTURE METER

34. Since it was first reported[7,8,9] about twelve years ago, that the water content of soil could be measured by a fast neutron scattering process, the apparatus required has been made in a form suitable for use in the field. Such portable apparatus may be purchased from perhaps ten manufacturers in several countries. Many users have made their own apparatus, according to the general layout shown in the block diagram in FIGURE II.

35. The probe houses a source of fast neutrons, which, after colliding with the protons of the soil water, diffuse back towards the probe as slow neutrons, there to be detected with a boron trifluoride counter tube. The circuitry is conventional, and employs proportional counting technique. The gamma-ray pulses associated with radium-beryllium neutron sources, must be rejected by the discriminator circuit.

36. Pulses caused by detection of slow neutrons are recorded, their rate of occurrence being proportional to the water content of the soil. The diameter of the probe is usually about 4 cm , and a number of investigators have described appropriate bore-hole installations. We prefer a bore-hole lined with black polythene tubing, 6.0 cm in outside diameter and having a wall thickness 0.48 cm [10]. Stolzy and Cahoon[11] discussed aluminium, steel and rigid plastic (P.V.C.) access tubes. The conclusion seems to be that aluminium or polythene access tubes should be preferred.

37. The volume of soil measured by the moderation of neutrons increases as the water content decreases. Its shape is approximately spherical, with diameter 40 cm at a water content 0.2 cc/cc. Mortier et al.[12] attempted to reduce, or control, the sample size and shape by shielding the counter tube, but their results and the work of others show that the sacrifice of counting rate for reduced sample volume is not worth while. In fact, a large sample size is often desirable.

38. Stone et al.[13] investigated the accuracy of the results to be expected from the neutron method of measuring water content. The standard deviation of an observation was largely contributed by the random fluctuations of the radioactive phenomenon. It is usually possible to make a measurement with a coefficient of variation of 1% in about 1 minute.

39. There is no limit, in principle, to the depth to which the water content may be measured. In practice, the drilling of a suitable bore-hole is sometimes difficult, when gravel or stones occur as strata in the soil. There should be no gaps between the bore-hole lining and the soil, not only because water may fill such a gap, causing

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7 Belcher, D.J., Cuykendall, T.R. and Sack, H.S., Civil Aeronautics Admin. U.S.A. Tech. Rep. No. 127 (1950).
8 Gardner, W.R., and Kirkham, D., Soil Sci., 73: 391-401 (1952).
9 Spinks, J.W.T., Lane, D.A., and Torchinsky, B.B., Canadian J. Technology, 29: 371-374 (1951).
10 Holmes, J.W., and Jenkinson, A.F., J. Agric. Engin. Res. 4: 100-109 (1959).
11 Stolzy, L.H., and Cahoon, G.A., Proc. Soil Sci. Soc. Amer., 21: 571-575 (1957).
12 Mortier, P., de Boodt, M., and de Leenheer, L., Zeit. f. Pflanzen. Düngung Bod., 87: 244-250 (1959).
13 Stone, J.F., Shaw, R.H., and Kirkham, D., Proc. Soil Sci. Soc. Amer., 24: 435-438 (1960).

an anomalous reading, but also because an air gap will cause the counting rate to be lower than it should be. The counting rate depends upon the diameter of the cavity in which the probe is placed, and calibration of the apparatus must include specification of the kind of access hole employed.

40. The neutron moisture meter has been used to measure the water content of soil in a variety of experiments with an agronomic aim. For example, Denmead and Shaw (private communication) investigated the rate at which soil moisture could be supplied to the roots of corn plants, as a function of soil water content. Cahoon et al.[14] measured the water content of soil mulched with wood shavings, compared it with a bare soil mulch, in citrus orchards, and showed little difference in the effectiveness of the mulch.

41. The technique is useful in the search for underground water supplies, by virtue of its ability to observe the deep infiltration of soil water through soil to the ground water table. It provides a method of assessing the recharge rate of ground-water aquifers, which may occur in permeable sediments. Nixon and Lawless[15] showed that the roots of "brush" species extracted soil water to a depth of 5 m on a deep sandy soil, whereas the same soil, when denuded of vegetation, transmitted much more water to the water table. Another example of an application of the method in hydrology is our own work[16] on infiltration of soil water in heathland soils, which will now, briefly, be described.

42. The soils investigated occur in the Upper South East of South Australia, within about 30 miles of the River Murray mouth. The profile has developed in deep sands, the relict dunes of former sea-beaches. The native vegetation, comprising Eucalyptus, Banksia, Xanthorrhoea and Casuarina species amongst many others in a heath-like community, has the ability to thrive, despite the very infertile soils and a summer drought lasting for about six months. Development of this land for pastures, by clearing and fertilizer application, was hindered by the lack of water. Groundwater occurs at about 13 m in the sands, but its quality is very variable. Our experiment intended to answer, amongst others, the question: how is the groundwater recharged?

43. Two sites were selected for study, one in a newly developed pasture of lucerne and annuals, the other in the native heath. A water-table observation bore at each site was incorporated in a grid of more than 100 observation bores. At each site, neutron moisture meter access tubes were drilled to a depth of 6 m. The soil water regime, during 1956 to 1958, was measured regularly. The result showed that infiltration of soil water to the water table was negligible under both heath and lucerne vegetation. An example of the employment of the soil water profile to make this decision is given in FIGURE III. Soil water evidently did not penetrate past a depth of 5 m — at Heath Site 3. The regime was not so unambiguous at some of the other sites, but the conclusion that the ground water was not recharged significantly by local infiltration of rainfall agreed also with water-table changes, which did not have an annual period. The whole investigation has been reported in three publications.[16,17,18]

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[14]Cahoon, G.A., Stolzy, L.H., and Morton, E.S. Soil.Sci., 92: 202-206 (1961).
[15]Nixon, P.R., and Lawless, G.P., J.Geophys. Res., 65: 655-661 (1960).
[16]Holmes, J.W., Aust. J. Agric. Res., 11: 970-988 (1960).
[17]O'Driscoll, E.P.D., and Shepherd, R.G., South Australia Dept. of Mines, Rep. of Investigations No. 15 (1960).
[18]Luthin, J.N., and Holmes, J.W., J. Geophys. Res., 65: 1573-1575 (1960).

44. Since 1959, the neutron moisture meter has been used to measure the water content of large lysimeter tanks 2m diameter by 2.4m deep, with successful results. This work is proceeding at present, in the Mount Gambier district of South Australia.

SURFACE GEOPHYSICAL PROSPECTING

45. In several of the larger sedimentary basins, surface geophysical methods of exploration have been used as an aid to the determination of structure. The most important of these is seismic work, and field parties have already covered large areas in several States. In general the results have been well worth while, although in places anomalies have occurred which have rendered interpretation difficult. In some instances, it has proved not possible to distinguish between Tertiary and Mesozoic sediments and the underlying Palaeozoic basement rocks. Despite the considerable expense involved, the Bureau of Mineral Resources and the South Australian Department of Mines are maintaining parties in the field, investigating several areas.

46. Electrical resistivity work, which has a limited application as regards depth, has not proved effective. In some areas it has been found impossible to distinguish between sands and shales at depths of less than 200 feet from the surface, even when the sands were water charged. In the Adelaide Plains in South Australia, the existence of a thin saline soil layer completely blanketed the underlying beds and no results were obtainable at all. Electrical resistivity methods appear to have little or no application to sedimentary stratigraphic investigations, at least in some parts of Australia, from a groundwater viewpoint.

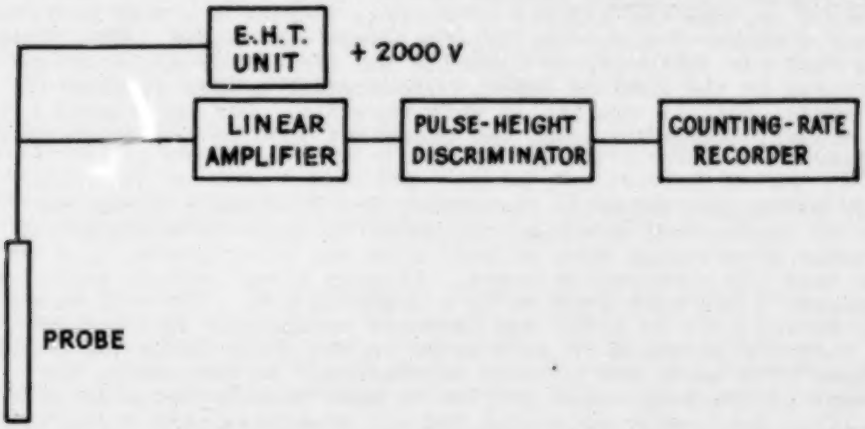


FIG. II – Diagrám of neutron moisture meter apparatus.

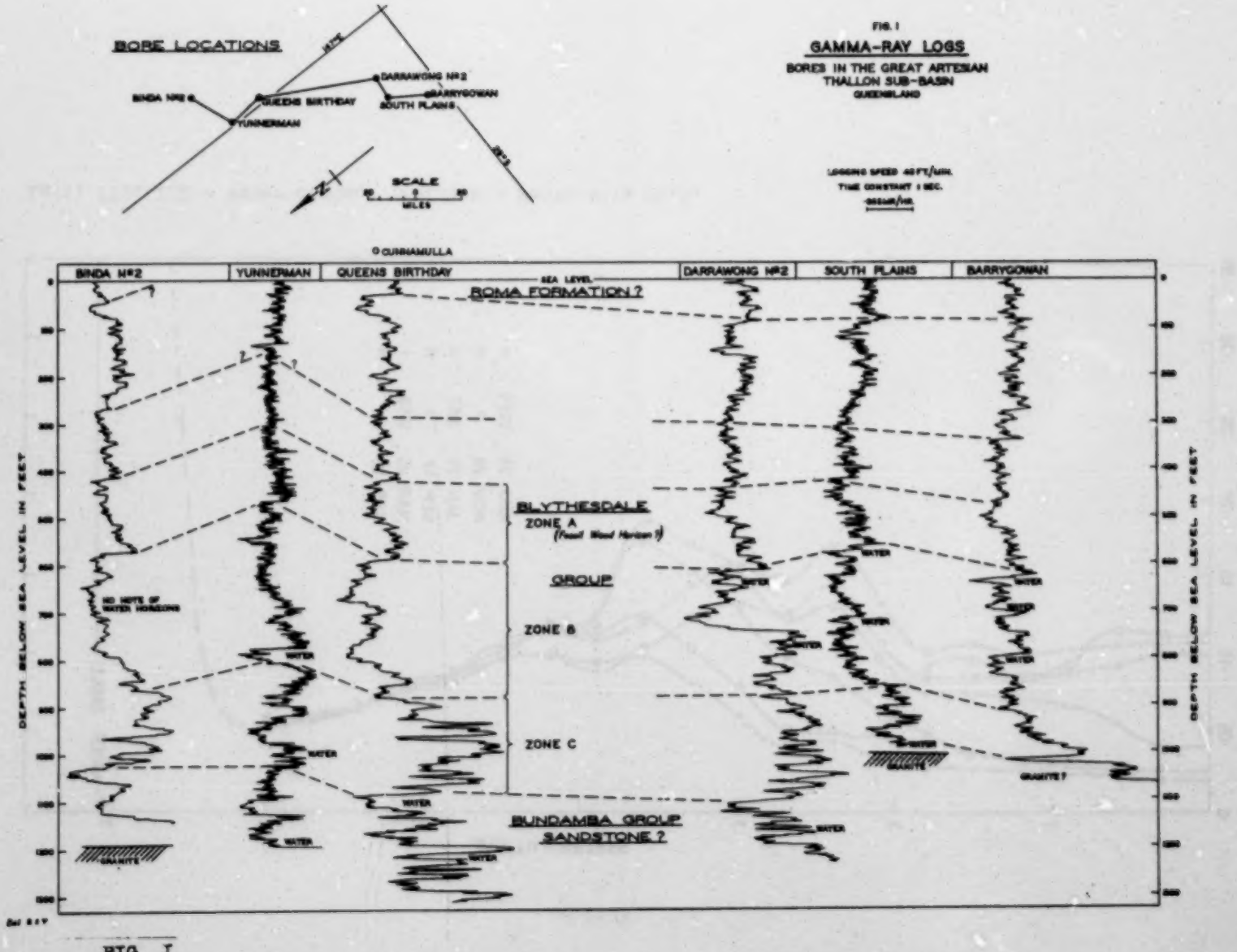
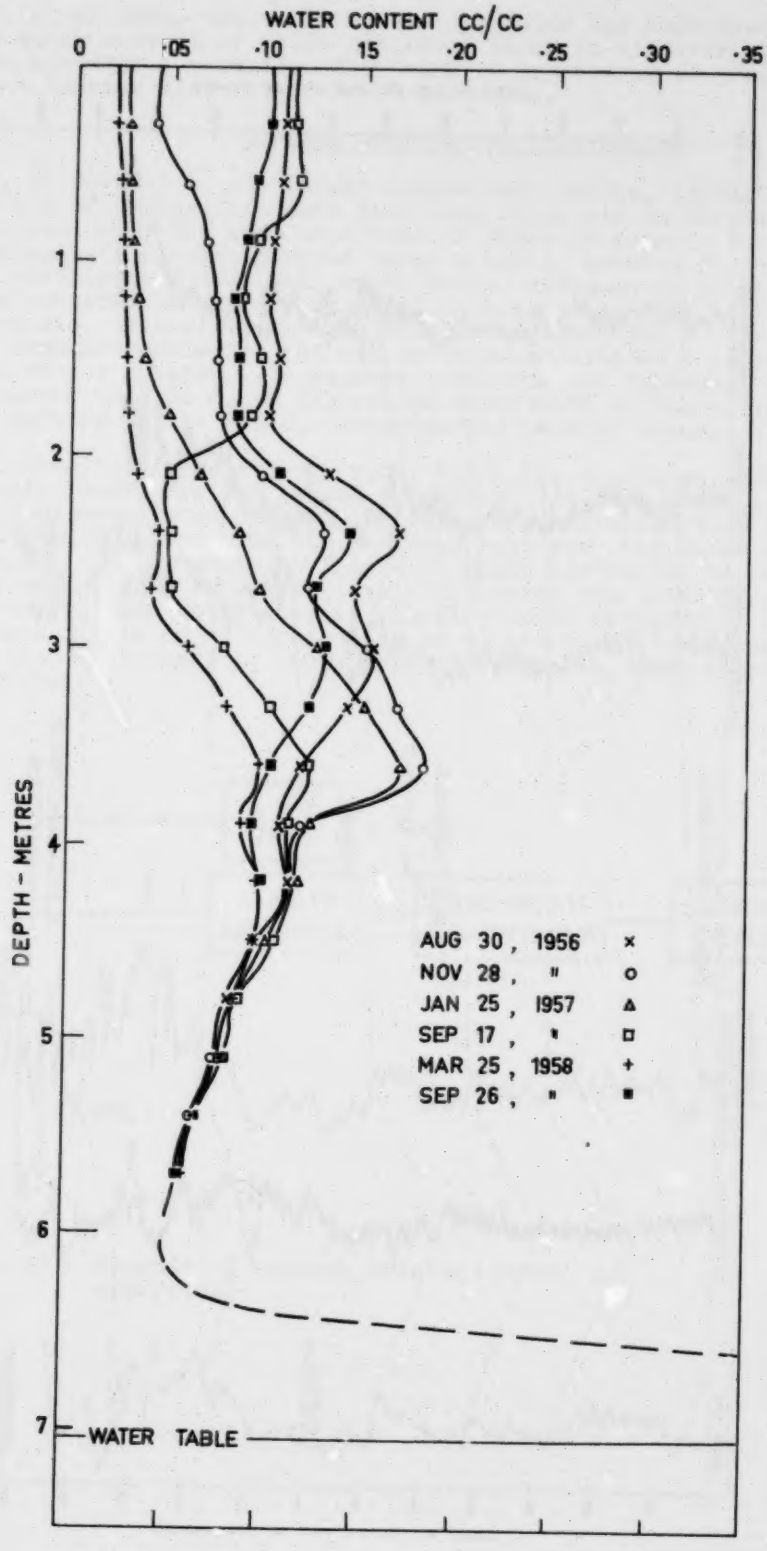


FIG. I

Gamma-ray logs showing a suggested correlation of six bores in the Great Artesian Basin



Left: FIG. III - Water content profiles - Heath site No.3.

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